NEP Mission Performance Technology Drivers

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NEP Mission Performance Technology Drivers

- NASA/MSFC Lead NEP Tiger Team II Vehicle Concept Starting Point

  We have to understand where we are in order to determine what technology advances are necessary!

- Technology Assumptions for Improved Performance
- Sensitivity of Neptune/Triton Mission Trip Times to
  - Decreased Dry Mass
  - Increased Thruster Efficiency
  - Increased Power
- The Physics Behind the Results
- Specific Electric Propulsion System Technology Challenges

Nuclear Electric Propulsion Tiger Team II

Team Members

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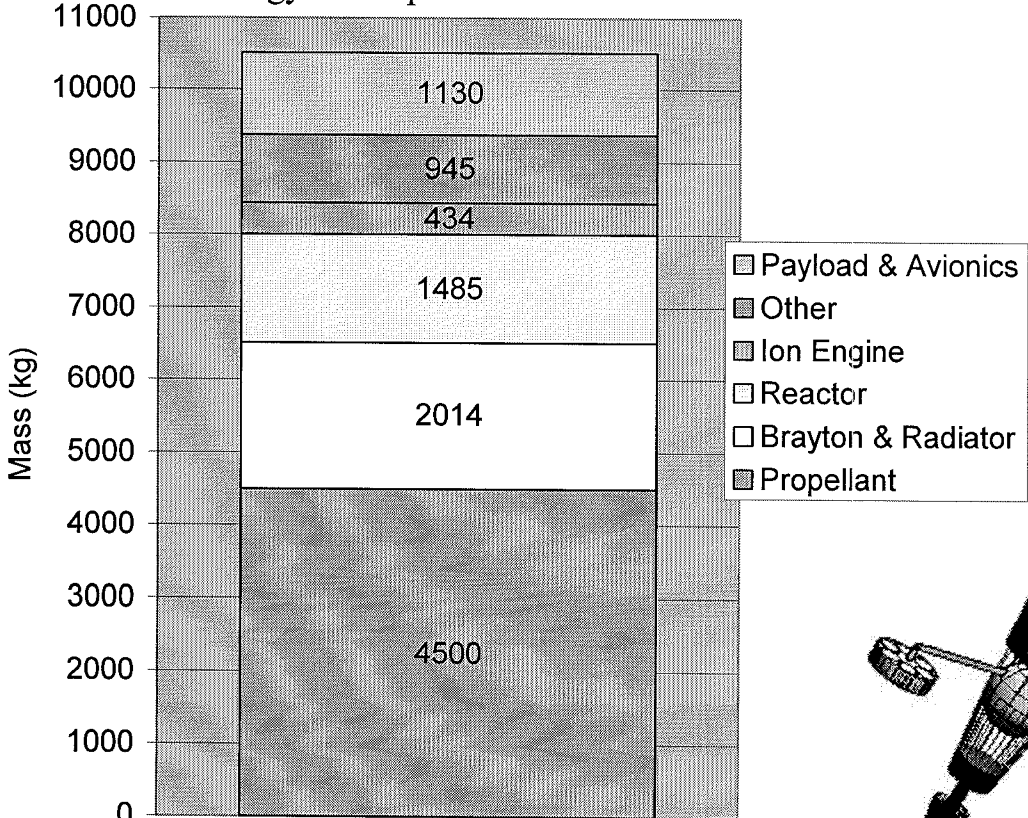
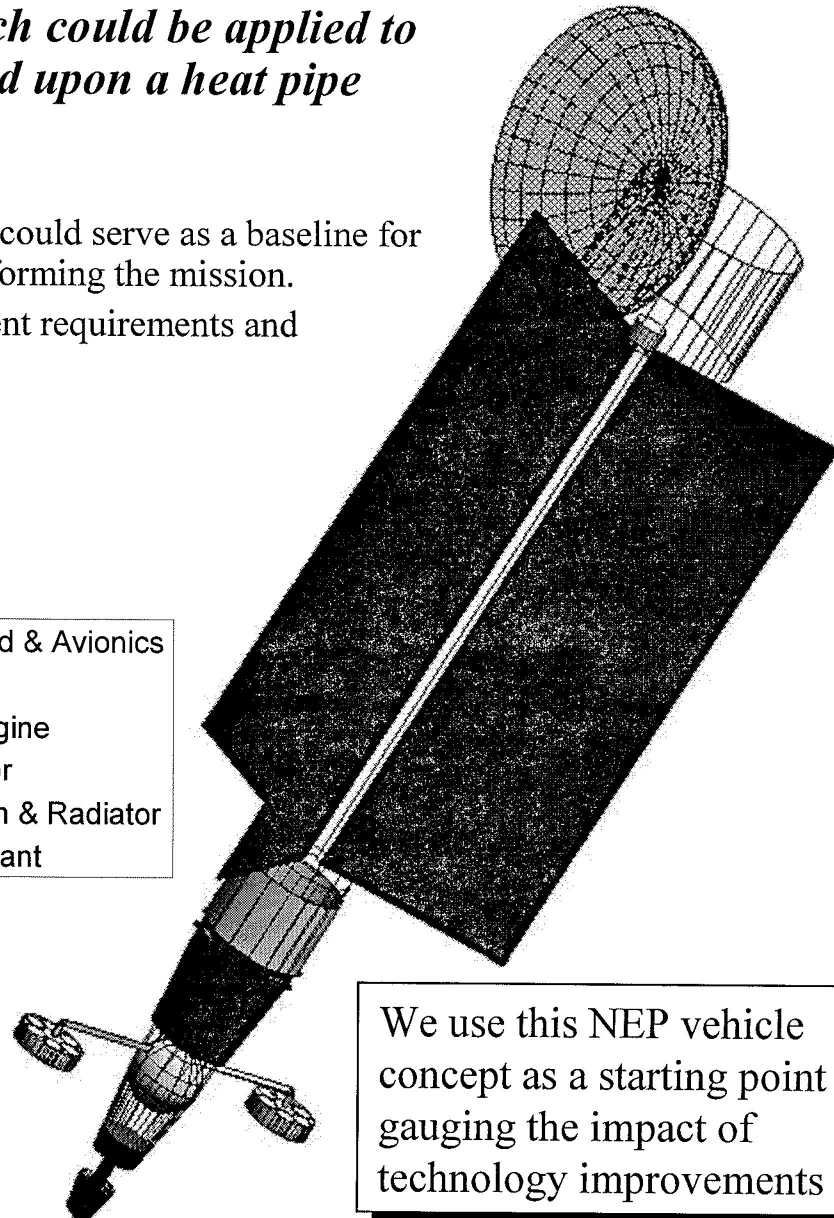
NEP Tiger Team II Vehicle Concept

An NEP spacecraft "point design", which could be applied to future trade studies, was generated based upon a heat pipe reactor, Brayton cycle and ion engines.

<u>Key Study Highlights</u>

1. This is an non-optimized spacecraft design that could serve as a baseline for future trade studies and has the potential of performing the mission.
2. Meeting the mass goal is difficult with the current requirements and technology assumptions.

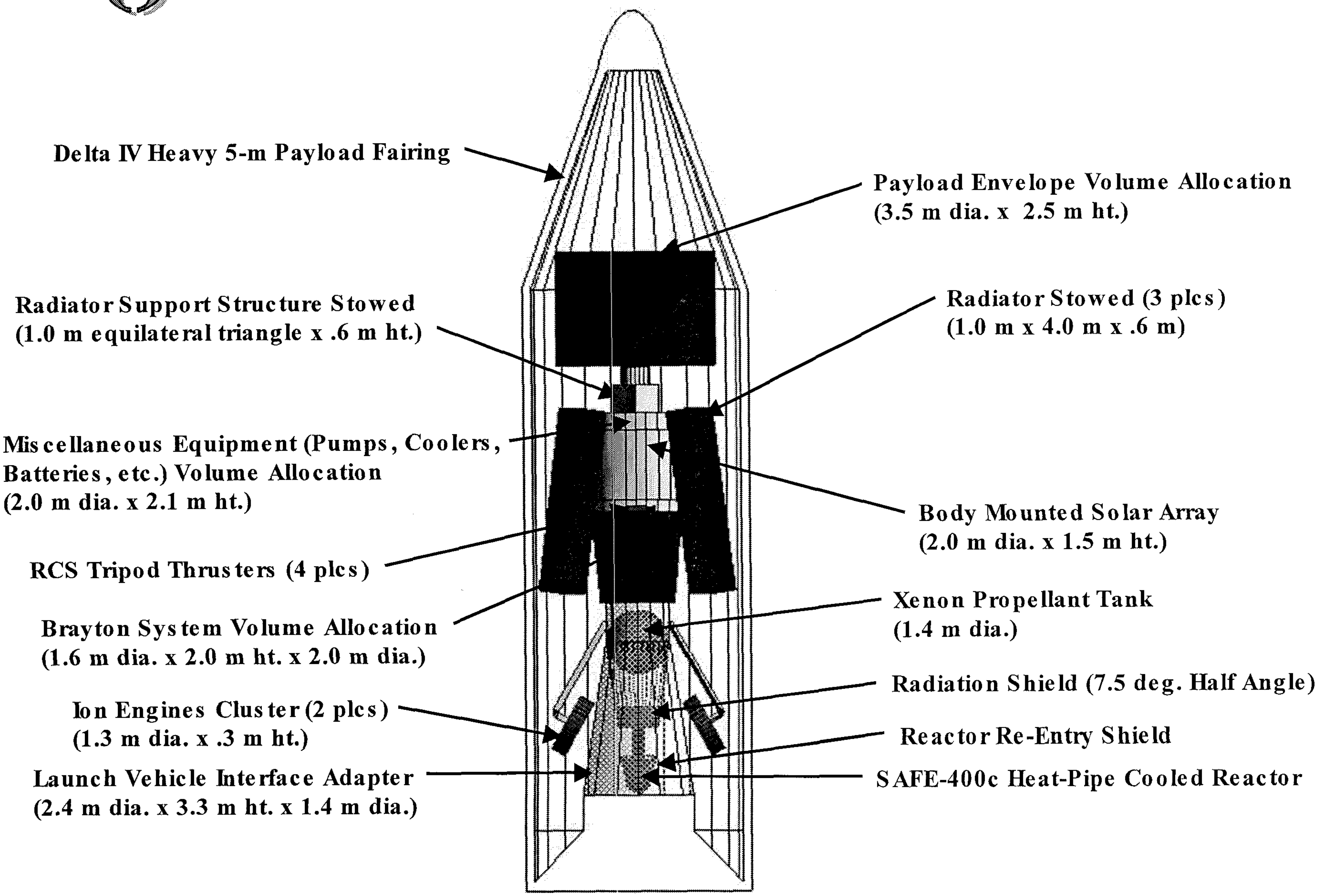




We use this NEP vehicle concept as a starting point for gauging the impact of technology improvements

NEP Tiger Team

Stowed Conceptual Configuration



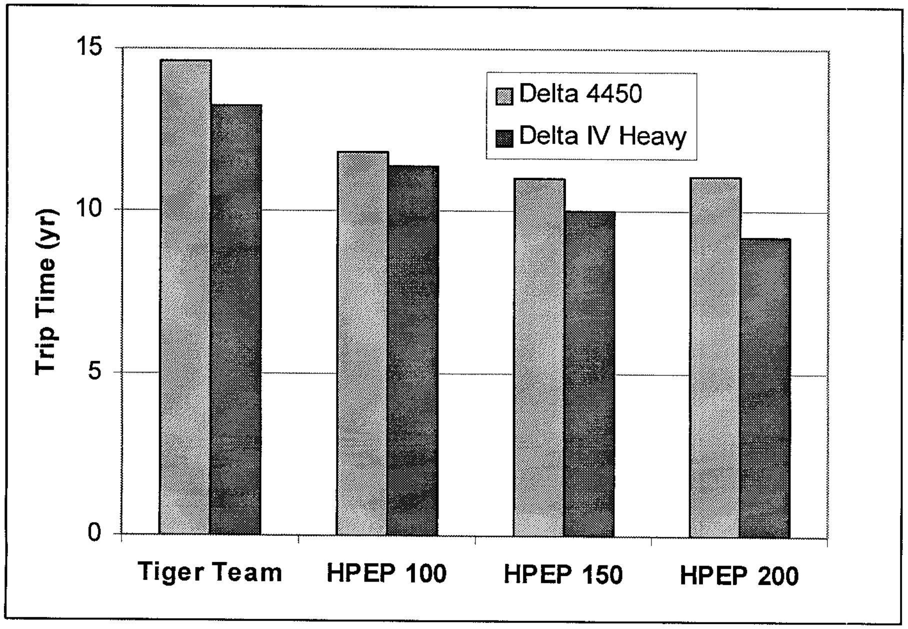
FRONT VIEW

High Power & Technology Improvements Needed to Achieve 10 Year HPEP Missions

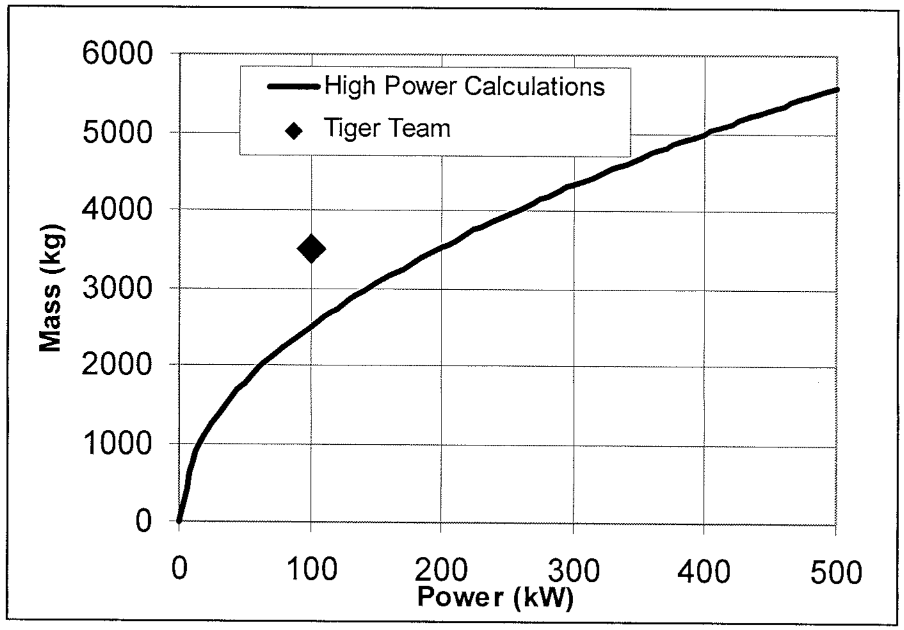
- Mission: Triton/Neptune
- Tiger Team Vehicle 14.6 Years
- 3 Approaches to Improved Trip Time
  - Power technology - reduced mass
  - Thruster efficiency
  - Higher power (square root scaling)
- All 3 needed to Achieve 10 Year Mission

Vehicle Assumptions

	Tiger Team	HPEP 100	HPEP 150	HPEP 200
Power	100	100	150	200
Power Mass	3500	2500	3062	3536
Total Dry Mass	5500	4500	5400	6160
Thruster Eff	73%	80%	80%	80%
PPU Eff	95%	95%	95%	95%
Efficiency	69%	76%	76%	76%
Trip Time (yr)				
Delta 4450	**14.6**	**11.8**	**11.0**	**11.1**
Minimum	**13.3**	**11.4**	**10.0**	**9.2**



Triton/Neptune Mission



Power System Mass

Technology Steps to Improve Performance

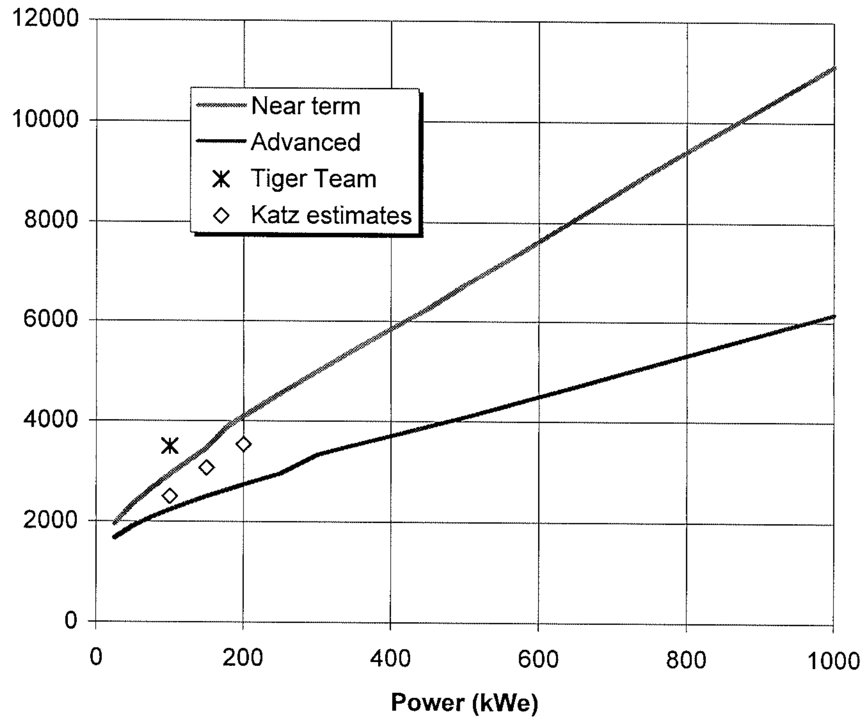
Technology choices that get us from:
3500kg/73% ➔ 2500kg/80%

- Tiger Team System
  - Reactor
    - Heat pipe with 3 exchangers
    - Reactor 650 kg
    - Heat Exchangers 213 kg
  - Power Conversion System
    - Three 40 kw Brayton system
    - Mass (inc. radiators) 2014 kg
  - Ion Engines
    - Xenon with individual neutralizers
    - Engine efficiency < 73.5%
      - Dec Tiger Team presentation

- HPEP System
  - Reactor
    - Gas Cooled Reactor
    - Mass saving ~163 kg
      - My estimate, no inputs
  - Power Conversion System
    - Single100 kw Brayton system
    - Mass saving ~800 kg
      - Extrapolating GRC converter size trade study in Tiger Team final report that showed ~ 400kg saving going from 3 to 2.
  - Ion Engines
    - Single neutralizer for multiple engines ~ 3-4% improvement
      - Has been demonstrated in laboratory test. Theory of space operation is being validated with DS1 flight data.
    - Improved discharge chamber propellant utilization~ 3-4% improvement
      - Competition sensitive new technology concept based on validated computer code simulations

GRC Power Scaling Projections

- Tiger Team Design Point
  - 3x35 kWe Brayton Engines
  - 1144 K Turbine Inlet Temperature
  - 25% System Efficiency
  - SAFE Heat Pipe Reactor + HSHX (1535 kg)
- Near Term Power Curve
  - 2 Brayton Engines at 50% Power
  - 1150 K Turbine Inlet Temperature
  - 21 to 24% System Efficiency
  - Liquid Metal Cooled Reactor (Scaled SP-100)
- Advanced Power Curve
  - 2 Brayton Engines at 50% Power
  - 1500 K Turbine Inlet Temperature
  - 30 to 34% System Efficiency
  - Liquid Metal Cooled Reactor (Scaled SP-100)



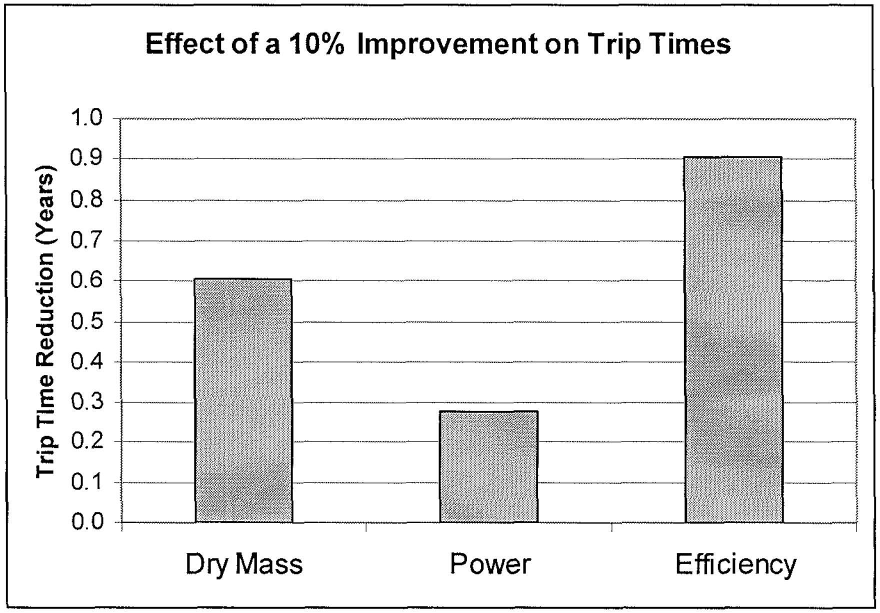
(Bob Cataldo & Lee Mason)

Sensitivity to Technology

- Baseline Assumptions:

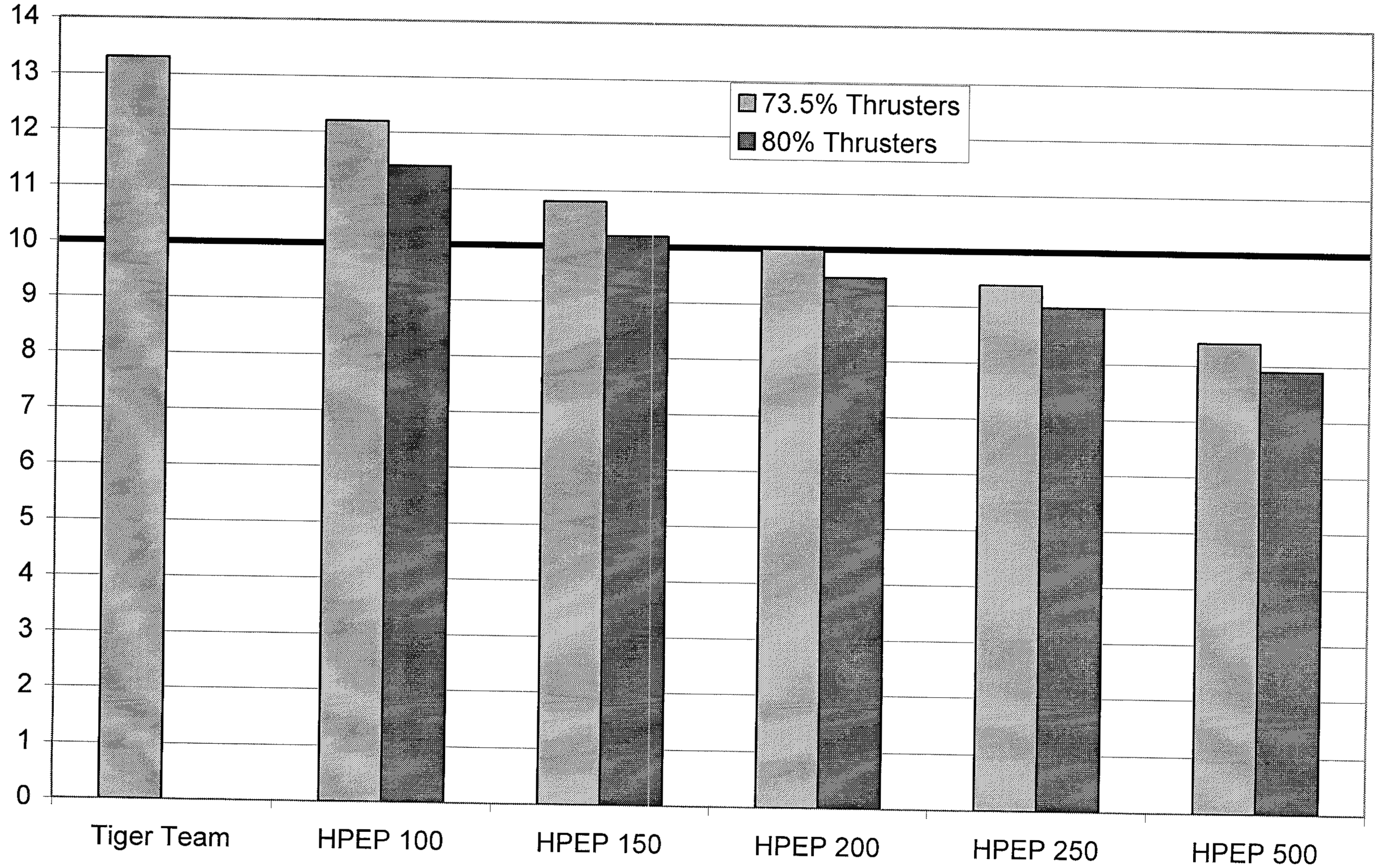
Payload	500kg
Power	3500kg
Propulsion	500kg
Other	1000kg
PPU Efficiency	95%
Thruster Efficiency	73%
Tankage + Margin	20%

- Enhanced Systems
  - Reduced power system mass
  - All masses except Payload scale with square root of Power

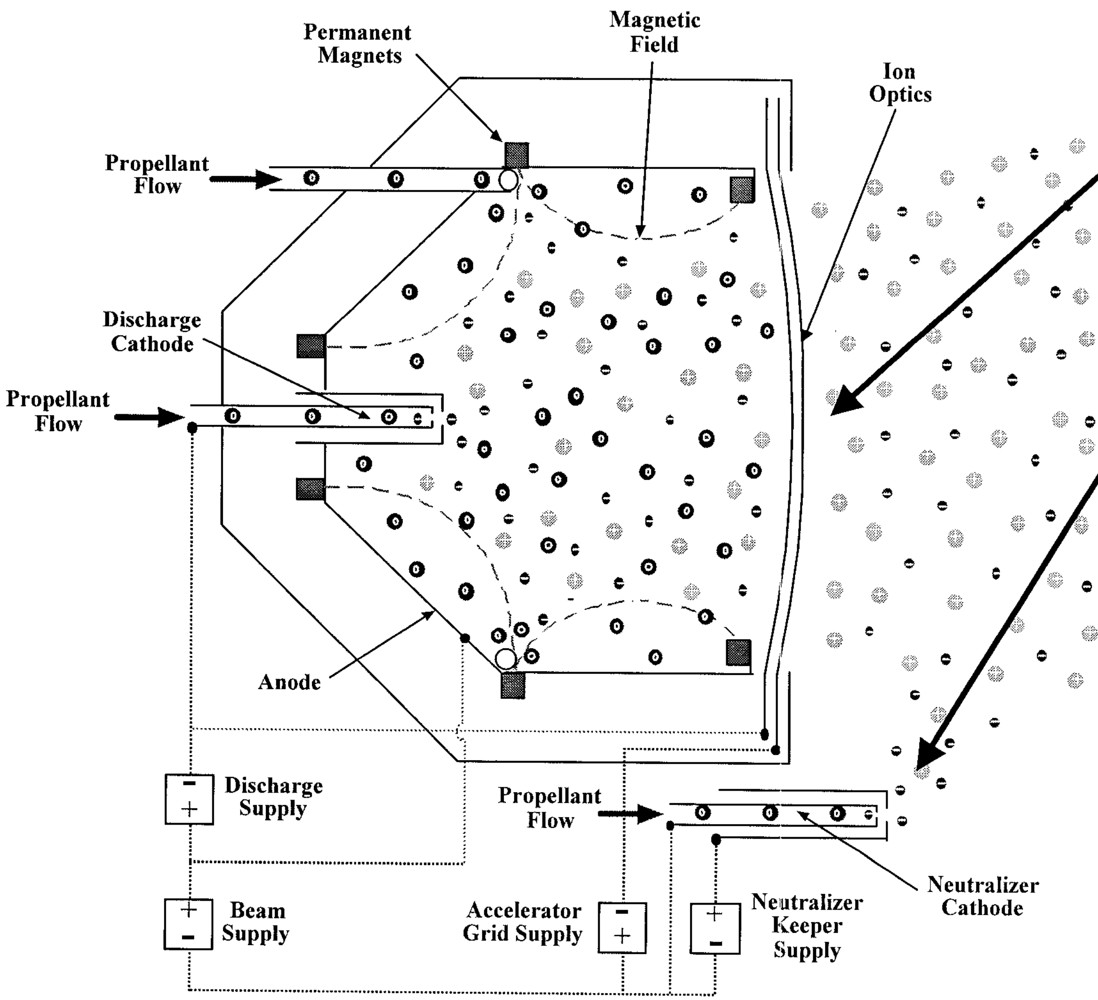


	Tiger Team	HPEP 100	HPEP 150	HPEP 200	HPEP 250	HPEP 500
Power	100	100	150	200	250	300
Power Mass	3500	2500	3062	3536	3953	4330
Total Dry Mass	5500	4500	5400	6160	6825	9440
PPU Eff	95%	95%	95%	95%	95%	95%
Thruster Eff	73.5%	73.5%	73.5%	73.5%	73.5%	73.5%
Efficiency	**70%**	**70%**	**70%**	**70%**	**70%**	**70%**
Trip Time (yr)						
Delta 4450	**14.6**	**12.6**	**11.4**	**11.6**	**11.6**	**11.6**
Delta IV Heavy	**13.3**	**12.2**	**10.8**	**10.0**	**9.4**	**8.4**
Thruster Eff		80.0%	80.0%	80.0%	80.0%	80.0%
Efficiency	**0%**	**76%**	**76%**	**76%**	**76%**	**76%**
Trip Time (yr)						
Delta 4450		**11.7**	**11.0**	**11.0**	**11.2**	
Delta IV Heavy		**11.4**	**10.2**	**9.5**	**9.0**	**7.9**

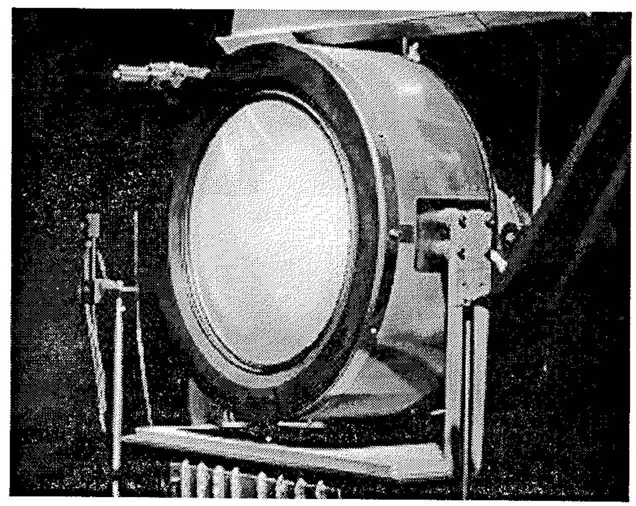
Effect of Technology on Triton/Neptune Trip Times



How Propellant Escapes From Ion Thrusters



1. Unionized gas escapes through holes in the grids
2. Ions and neutral gas come out of the hollow cathode neutralizer



Engineering model ion thruster built by NASA GRC during 8200 hour endurance test at JPL.

Propellant Utilization Helps Performance

- Newton's second law describes NEP vehicle motion

$$m\mathbf{a} = \mathbf{F}$$

$$m\frac{d\mathbf{v}}{dt} = \dot{m}\overline{\mathbf{v}} = \dot{m}\,(f_{beam}\mathbf{v}_{beam} + (1 - f_{beam})\mathbf{v}_{gas})$$

$$\approx \dot{m}\ f_{beam}\mathbf{v}_{beam}$$

- If we consider dry mass and propellant masses, we can integrate to get the rocket delta v

$$m\frac{d\mathbf{v}}{dt} = \frac{dm}{dt} f_{beam}\mathbf{v}_{beam}$$

$$\int_{v_0}^{v_f} \frac{dv}{f_{beam}v_{beam}} = \int_{m_{dry}+m_{prop}}^{m_{dry}} \frac{dm}{m}$$

$$\Delta v = f_{beam}v_{beam} \ln\left(1 + \frac{m_{prop}}{m_{dry}}\right)$$

NOTE: Δv is proportional to propellant utilization, f_{beam}

Trip Times Decrease Slowly With Increased Power

- Time is roughly proportional to the square root of the acceleration

$$\mathbf{a} \approx \frac{\dot{m}\ f_{beam}\mathbf{v}_{beam}}{m}$$

$$t_{trip} \propto \sqrt{\frac{m}{f_{beam}}}$$

Same Dependence on Mass, Propellant Utilization

- For a fixed *Isp*, the thrust is proportional to the beam power

$$P_{beam} = \tfrac{1}{2}\ \dot{m}\ f_{beam} v_{beam}^2$$

- If the mass increases with the square root of the power

$$\mathbf{a} \propto \frac{P}{m}$$

$$t_{trip} \propto \sqrt{\frac{m}{P}}$$

$$t_{trip} \propto \frac{1}{P^{1/4}}$$

Requirements for 10 Year Neptune Orbiter Trip

- Back of the envelope estimate

distance	30	AU
	4.5E+09	km
time	10	years
	3.3E+08	seconds
v average	14	km/s
delta v	**54**	**km/s**

- We assume burn time is 2/3 of trip time & rest of system is 88% efficient

- 100 kW system inconsistent with 10 yr trip time

Assumed Power (kW)	**100**	**100**	**100**	**100**
Dry Mass (kg)	5,500	5,500	4,500	4,500
Launch Mass (kg)	14,000	14,000	11,250	11,250
Propellant Utilization	80%	90%	80%	90%
Required Power (kW)	**168**	**133**	**137**	**109**

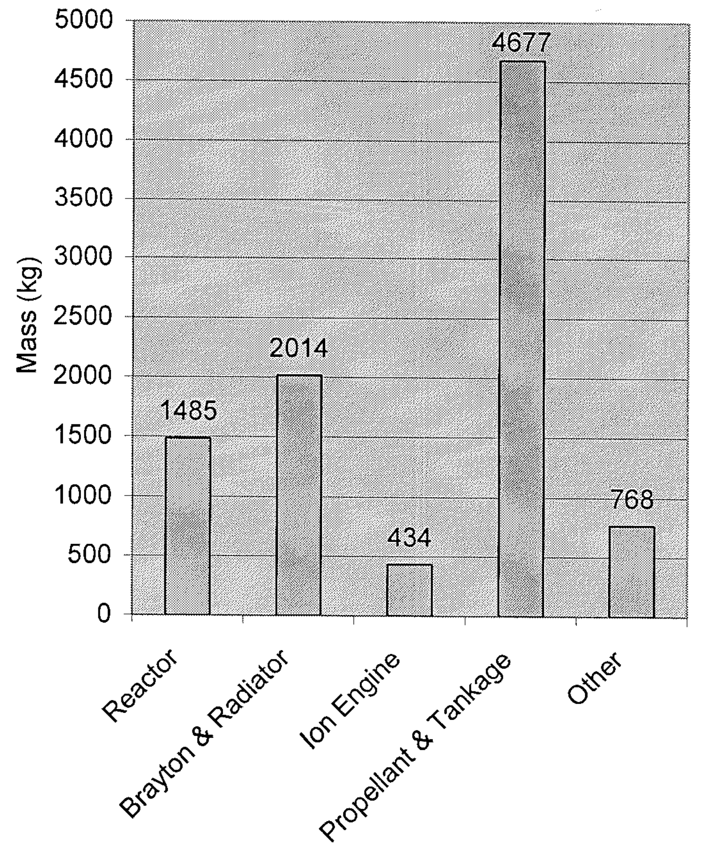
- Improved utilization & higher powers necessary

100kW Dry Mass	5,500	5,500	4,500	4,500
Propellant Utilization	80%	90%	80%	90%
Break Even Power	**300**	**225**	**200**	**150**
Launch Mass	24,000	21,000	16,000	14,000

Electric Propulsion System Technology Advances That Would NEP Improve Performance

Subsystem	Potential Mass Saving
• Propellant utilization	
Reducing discharge chamber propellant losses by tailoring grid holes to local beamlet diameters	~4% of propellant ~ 200 kg
Single neutralizer for several engines	~4% of propellant ~ 200 kg
• Propellant management	
Improve precision of flow controller from 3% to 1%	~ 2% of propellant ~ 100 kg
• Propellant tank	
Ultra-light weight Xenon tank, reducing tankage from 6% to 3%	~ 3% of propellant ~ 150 kg
• Engine life	
Long life, erosion resistant, high voltage grids	~ 150 kg
Extended life hollow cathode	

Propellant is the "Long Pole"



Potential Launch Mass Savings of 500-1000 kg!

NEP Mission Performance Technology Drivers

- Only three ways to improve NEP Vehicle performance
  1. **Reduce dry mass**
  2. **Reduce propellant waste**
  3. **Increase power – take advantage of reactor/power system scaling**
- Electric propulsion system technology advances needed

  Improved propellant utilization – grids & neutralizers

  Improved flow control accuracy

  Ultra-lightweight Xe tanks

  Increased life high *Isp* grids

  Increased life hollow cathodes
- Radiator packaging in the launch vehicle shroud identified as the leading impediment to higher power systems